AFRL-ML-WP-TR-2000-4015

DISCONTINUOUSLY REINFORCED METALS

INDUSTRY ASSESSMENT

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SEPTEMBER 1998

FINAL REPORT FOR SEP 1997 – SEP 1998

MATERIALS AND MANUFACTURING DIRECTORATE
AIR FORCE RESEARCH LABORATORY
AIR FORCE MATERIEL COMMAND
WRIGHT-PATTERSON AIR FORCE BASE OH 45433-7750

REPORT DOCUMENTATION PAGE

1. REPORT DATE (DD-MM-YYYY) 01-09-1998	**2. REPORT TYPE** Final Report	**3. DATES COVERED (FROM - TO)** 16-08-1995 to 06-01-2000
4. TITLE AND SUBTITLE Discontinuously Reinforced Metals -- Industry Assessment Unclassified		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHOR(S) Henderson, John G. ; Gunderson, Allan W. ; Hjelm, Larry ; Riviello, Craig ; Wawner, Franklin ;		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME AND ADDRESS Universal Technology Corporation 1270 N. Fairfield Road Dayton , OH 45432-2600		**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS Materials and Manufacturing Directorate Air Force Research Laboratory Air Force Materiel Command Wright Patterson AFB , OH 45433-7750		**10. SPONSOR/MONITOR'S ACRONYM(S)** AFRL/MLLM **11. SPONSOR/MONITOR'S REPORT NUMBER(S)** AFRL-ML-WP-TR-2000-4015
12. DISTRIBUTION/AVAILABILITY STATEMENT		

A
PUBLIC RELEASE

Materials and Manufacturing Directorate
Air Force Research Laboratory
Air Force Materiel Command
Wright Patterson AFB , OH 45433-7750

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report documents the results of an assessment to determine avenues of development efforts appropriate for discontinuously reinforced metal matrix composites. The assessment followed the successful Title III funded program to productionize the discontinuous reinforced aluminum (DRA) materials with the desired end result of structural applications in aerospace hardware. This assessment went beyond the DRA materials to search out needs and applications for discontinuous reinforced magnesium, titanium, and high temperature aluminum matrices. The focus for the assessment was to provide AFRL/ML with aerospace industry interest and concerns which could guide future development activities

15. SUBJECT TERMS
Metal matrix composites, discontinuous reinforced metals, aircraft structural composites, spacecraft structural composites, materials assessment, metals production techniques

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
			Public Release	23	Fenster, Lynn lfenster@dtic.mil
a. REPORT Unclassified	b. ABSTRACT Unclassified	c. THIS PAGE Unclassified			19b. TELEPHONE NUMBER International Area Code Area Code Telephone Number 703 767-9007 DSN 427-9007

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	SEPTEMBER 1998	FINAL REPORT FOR 08/16/1994 - 01/06/2000

4. TITLE AND SUBTITLE

DISCONTINUOUSLY REINFORCED METALS -- INDUSTRY ASSESSMENT

5. FUNDING NUMBERS

C F33615-94-C-5800
PE 62102
PR 2418
TA 00
WU LS

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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10. SPONSORING/MONITORING AGENCY REPORT NUMBER

AFRL-ML-WP-TR-2000-4015

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APPROVED FOR PUBLIC RELEASE, DISTRIBUTION UNLIMITED.

12b. DISTRIBUTION CODE

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15. NUMBER OF PAGES

23

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

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1. BACKGROUND

Discontinuously Reinforced Aluminum matrix composites (DRA) have recently achieved maturity through the Air Force Title III program which scaled up the billet product, demonstrated various structural shapes and components, demonstrated a significantly reduced production cost, and developed design data (MIL-HDBK-5) [References 1, 2]. As a result, a number of production applications have been identified, from aircraft structure to turbine engines. Experience with DRA indicates that significant increases in yield strength, modulus, high temperature properties, etc., can be developed while maintaining adequate ductility and toughness.

The Title III program was focused on powder metallurgy processing to obtain the highest performance composites. A concurrent development using SiC particulate additions to a standard molten metal/cast ingot process approach has been developed by the Alcan Corporation. This process yields a significant overall cost reduction, albeit with some reduction in mechanical properties. The Alcan material is aimed at the auto market, where it competes with cast iron and steel. There, a low cost, lightweight material with modest property improvements and excellent wear resistance is appreciated. The properties developed are not sufficient to compete with aerospace Al, G/Ep, and Ti, and therefore they have not generated enough interest to be pursued for aerospace applications.

The successes with DRA has raised the interest in other discontinuously reinforced metals (DRX) and opened the question of where else research and development could produce inexpensive advanced discontinuously reinforced metal matrix composites of value to the aerospace community and the Air Force.

An initial assessment of available data was made and two clear leaders, in addition to DRA, came out as having potential applications for aircraft, engines, missiles, and spacecraft, as well as nonaerospace applications. These materials are high temperature DRA (HTDRA) and discontinuously-reinforced Ti (DRTi).

Discontinuously-reinforced magnesium (DRMg) has properties including higher stiffness and increased tensile strengths over normal magnesium. Early experiments with silicon carbide particulate-reinforced magnesium at ARCO (presently ACMC) showed that 50-100% improvements in yield strength and modulus could be achieved, depending upon the magnesium alloy. These materials would be competitive with graphite/epoxy materials and may be preferred in some applications such as electrical grounding planes or in a high wear location. However, poor fracture properties were a barrier for many potential applications. Sample properties are shown in Table 1.

For high strength and higher temperature applications, DRTi materials appear to have much potential [Reference 4]. In Table 1 it can be noted that the addition of 10% TiB increases the modulus by 21% (16 msi to 19.4 msi) and the yield strength by 15% (128 ksi to 147 ksi). The increased specific stiffness could have the highest payoff in nonrotating, and possibly rotating, engine structure applications, as well as high temperature aircraft and missile structures, control surfaces and rocket components. Dynamet Technologies Inc., in Burlington, MA has been developing and producing DRTi for many years using sponge fines and master alloys in a blended elemental approach. Early material suffered from very poor fatigue properties due to the residual NaCl in the sponge fines. Recent publications have reported markedly improved properties. Toyota Research & Development Labs have been developing and evaluating DRTi for some time. Recent publications have shown very promising results with blended elemental approaches to a TiB particle-reinforced titanium alloy [References 5-9]. Low cost could be achieved with blended elemental powders using titanium sponge fines, pre-alloyed powders, or an improved ingot metallurgy approach.

Table 1. Room Temperature Comparison of Particulate Reinforced Extruded Metals

	Al 6092/SiC/ 25p	Al 6092/SiC/ 17.5p	Mg ZK60A/ SiC/20p	Ti 6-4/ TiC/10p
Density (lb/in^3)	0.102	0.101	0.076	0.161
Y.S. (ksi) / Specific Y.S.	61 / 598	61 / 604	61 / 803	130 / 807
Mod (msi) / Specific Mod	17.7 / 174	15.6 / 155	12.1 / 159	19.3 / 120
Elongation (%)	5	6	<2	5
References	2	2	3	4

2. SURVEY OF INDUSTRY INTEREST

The Air Force Research Laboratory, Materials and Manufacturing Directorate, Metals, Ceramics and NDE Division, Metals Development and Materials Processing Branch (AFRL/MLLM), with the assistance of Universal Technology Corporation (UTC), conducted a survey to determine if the interest in low cost magnesium or titanium metal matrix composites, and expanded HTDRA is sufficient to stimulate renewed funding in this area. Emphasis was placed on determining if there were significant aerospace applications to justify additional development.

This survey was conducted in two phases. The first phase, conducted by UTC, involved interviews with over 50 industrial contacts to screen initial interest in the development of DRX materials and processing. The second phase, conducted by AFRL/MLLM, was a detailed look at potential applications for DRX in specific industries showing high interest in the first phase. This report documents the results of the first phase of this assessment. Results from the second phase will be issued at a later data as a separate report.

Suppliers Dynamet Technology, Inc. Sparta, Inc. Alcoa Specialty Metals Division Alyn Corporation Technirep, Inc. DWA Composite Specialties, Inc. **Aircraft** Lockheed Martin Tactical Aircraft Systems Lockheed Martin Aeronautical Systems McDonnell Douglas Aerospace Boeing Defense & Aerospace Boeing Commercial Airplane Group **Government** Naval Surface Warfare Center Aeropropulsion & Power Directorate Army Research Laboratory Office of Naval Research NASA Lewis Research Center Flight Dynamics Directorate Naval Air Warfare Center	**Turbine Engines** Pratt & Whitney AlliedSignal Allison Engine Company General Electric Aircraft Engines **Automotive** Ford Motor Company General Motors **Hypersonics** Pratt & Whitney **Rockets** Atlantic Research Corporation Rocketdyne Boeing North American **Space** McDonnell Douglas Aerospace Applied Material Technologies Triton Systems Inc. Boeing Commercial Airplane Group **Electronics** Roush Anatrol

Figure 1. Metal Matrix Composites Industry Perspective

Organizations contacted in the first phase are shown in Figure 1. Both aerospace and nonaerospace organizations were contacted. The purpose of contacting nonaerospace organizations was to obtain an indication of potential dual use opportunities for these materials. Specific questions were addressed in the first phase of this survey including:

- Would you anticipate using materials with properties similar to those shown in Table 1 if they were available?
- If so, for what types of applications?
- What properties are drivers for your applications; i.e., strength, modulus, abrasion resistance, etc.?
- What range of temperatures would be required for your applications?
- The properties presented in this summary are from a small database and small design program. What other properties, based on your design criteria, would provide an attractive total balance of material properties for the various applications that could be solved by this development effort?
- A change in alloy systems can have a remarkable change in resultant properties. Have any of the alloy systems that you are currently working with exhibited these characteristics which could be translated to a discontinuously-reinforced metal?
- What approximate cost premium would you pay in your applications to gain these performance advantages?

3. INDUSTRY PERSPECTIVE

3.1 Aircraft Structures

One of the most dominant design properties in aircraft structures is the material modulus, which can influence as much as 50-70% of the structure weight. Other design considerations include cost, damage tolerance, density, yield strength, stress corrosion, high temperature behavior, fatigue response and behavior under thermal cycling. Several respondents identified issues with a drop in toughness and ductility as levels of reinforcement are increased. The airframe respondents were generally in agreement that they would use alloys with the properties listed in the questionnaire, provided that a balance of other properties and cost requirements were met. One respondent thought the DRTi properties listed did not look as attractive as DRA and DRMg properties. Some concern was expressed that the "niche" materials did not get the attention early in the aircraft design cycle and that the companies needed to concentrate on the "big ticket" items. This implied that DRX and similar materials needed government support to transition to design application.

DRA is currently being utilized in the F-16 ventral fin replacement. Additional potential applications identified would take advantage of the modulus increase: long, stiff supports, extruded products for stringers and frames, floor panels and supports. Ti alloys are used in many applications (pylon and wing structures in transport aircraft and engine support structures in fighter aircraft) since the use temperature is slightly above the maximum use temperature of Al alloys (~150°C). A weight and cost penalty exists for these applications, and there was strong interest in replacing these components with HTDRA. Both HTDRA and DRTi were viewed as possible replacements for Ti and 700°F organic matrix composites. One respondent pointed out that literally "acres of extruded stringers" would be a choice application, especially for DRA. Magnesium alloys have been ruled out of consideration for the JSF structure because of Navy concerns about corrosion. One company thought that DRMg could beat out Beryllium-Aluminum in stiffness for applications such as avionics racks. Vehicles identified were fighter and high speed aircraft, and hypersonic vehicles; these will all have a spin-off to commercial applications if cost effective. Fabrication technology needs include economical sheet, forgings, castings, SPF/DB, and weld processes. Temperature requirements reported ranged from –65°F to 700°F. DRTi or HTDRA would be required to satisfy the high temperature requirements.

One respondent judged the benefit of weight saved to be worth between $250-500 per pound. This would have to pay for all insertion costs including design data. Another respondent estimated that the premium for the advanced properties would be worth a 10-20% cost increase, dependent on design requirements. Several respondents discussed the importance of secondary processing costs. A summary of feedback from the aircraft structures industry is shown in Figure 2.

Strength, modulus and damage tolerance are strongest drivers in aircraft design

- — DRA currently being used in F-16 ventral fin replacement
- — DRTi has possible applications above the temperature limit of Al
- — HTDRA can replace Ti at temperatures between 150-190°C, saving both cost and weight
- — DRMg ruled out of Navy aircraft, so not much interest for JSF
- — Affordability is a major materials selection input

ASSESSMENT: DRX materials have definite applications in aircraft structures. HTDRA and DRTi have high potential for significant use.

Figure 2. Aircraft Applications For DRX

3.2 Space Structures

Space structures have two major design criteria, launch loads and on-orbit loads. The largest loads are generally from the launch environment, with a high “G” loading and high sonic loading. Generally, these are designed to the tensile strength and compressive strength of the material. The on-orbit loads are generally low and are from two major sources, satellite maneuver loads and orbital thermal loads from passing in and out of the earth’s shadow. Higher modulus materials reduce maneuver strains (and therefore satellite pointing distortion). Specific stiffness improvements raise the natural frequency of the structure and aid in reducing dynamic distortion. Being nearly impervious to the space environment aids designing for long life structures. Atomic oxygen bombardment and micrometeorite impacts, as well as the van Allen radiation belt, add to the environment challenge. In addition, thermal conductivity and thermal stability are important for long term orbital service. A bonus for metallic structures is the electrical continuity, which is useful in creating a ground plane for the whole structure. Most interest was expressed in the DRA materials because of the property blend, which included higher corrosion resistance than Mg and lower density than Ti composites with about the same modulus. Ti composites hold lesser interest, although applications may arise in launch vehicles. DRMg has been used successfully in demonstrations in the Strategic Defense Initiative program and improved alloys would add to the corrosion resistance.

To take maximum advantage of the modulus increase, most DRX applications would concentrate on support structure, stiffness driven components such as tube framework and truss structure for space station, solar cell panel backup structure, antenna support structure and launch support structure. Product forms include tubular extrusions, castings for connecting node hardware and sheet products for larger panel assemblies. Advanced fabrication requirements include semi-solid metal working, super plastic forming often combined with diffusion bonding, and welding techniques. The temperature excursions for most compact satellites can be controlled fairly closely by use of thermal blankets and insulation techniques. External structural parts and solar power cell structures in near earth orbit can expect thermal excursions from –150°F to +230°F depending on thermal absorbtivity/radiation. Midearth orbit and geo-synchronous satellites reach temperatures down to –250°F.

The launch cost per pound depends primarily on the orbit in which the structure is to be placed. One respondent estimated a range of $10,000 to $50,000. Another estimated geosync satellites cost around $20,000 per pound launch cost. Yet another respondent would be willing to pay a premium of 2-3x over graphite epoxy if they needed the electrical properties available with metals. Caution in the use of these values was expressed because the entire production costs must be taken into account, not just the up-front material costs. Another cost driven application is for the replacement of beryllium materials, made difficult by the superb properties of Be for space applications but easier because of the toxicity issue with Be.

The overall assessment of the space industry indicates the strongest support for the DRA materials for improved structures and Be replacement. Support also is strong for the DRMg development as a longer-term replacement for Gr/Ep materials. DRTi is supported for specialized application in launch support environment and possible precision antenna support structure where other materials are strength limited. Development needs center around wide spectrum property development with added emphasis on micromechanics understanding. Thermal cycling fatigue properties are needed for long duration satellite life prediction. A summary of feedback from the space structures industry is shown in Figure 3.

Space structures driven by performance, not material cost

- Launch costs of $10–50K per pound overwhelms material purchase cost
- Launch loads require high tensile and compressive capabilities
- On-orbit loads require modulus, thermal properties (CTE, conductivity)

DRA most promising for near term applications

- DRTi may have launch load applications
- DRMg low density holds promise for the future

ASSESSMENT: With improvements in processing and enhanced databases all DR metals appear to have increased usage in satellites and ancillary hardware. Marketing to this industry directly will heighten technology transfer.

Figure 3. Space Applications For DRX

3.3 Aircraft Turbine Engines

DRX is not viewed as a solution to the high priority turbine engine design challenge of damage tolerant and fatigue resistant rotating components. However, there is some interest in application of DRX in static components that are not fracture critical. DRA is currently being used by Pratt and Whitney in fan exit guide vanes for the 4XXX series of engines, with a significant improvement in life and affordability over the previous baseline material (graphite/epoxy). One respondent showed considerable interest in both conventional and HTDRA as well as DRTi. Other respondents talked of possible applications but with limited enthusiasm. There was no interest expressed for DRMg.

Potential applications for DRA include stators, containment rings, cases, actuator rods, and transmission cases. HTDRA could be a replacement for costly high temperature organic matrix composites (OMC's). Erosion and foreign object damage (FOD) resistance were of interest. DRTi has possible application in actuator pistons, rings, tie rods, bellcranks, links, shafts, and ducts.

One respondent felt that cost per pound was an inappropriate metric for the engine community. Materials must compete on a materials cost and manufacturing cost to produce a component. The material system that results in the lowest component cost is the proper cost metric. Another respondent felt that $500/pound was a reasonable goal. A summary of feedback from the aircraft turbine engine industry is shown in Figure 4.

Limited interest identified

- One engine manufacturer interested in HTDRA and DRTi
- Navy interest in HTDRA for advanced engines (IHPTET)

Many suggested applications

- Stationary parts for weight savings, e.g. stators, cases, etc.
- No rotating parts

Need to compete with high temperature OMC

ASSESSMENT: Limited interest within engine community, although HTDRA and DRTi show promise of significant improvements in weight and affordability

Figure 4. Turbine Engine Applications For DRX

3.4 Hypersonic Vehicles, Missiles, and Rockets

These three segments of the aerospace industry have similar interests in materials centered on problems associated with very high temperatures. DRTi is of some interest for small parts such as missile fins and small rocket motor cases. There is some interest in DRA. DRA is currently being certified for an opto-mechanical assembly in an advanced Army missile. The AF has a requirement for very high strength aluminum with outstanding properties at cryogenic temperatures for a liquid hydrogen (LH2) pump. While this application represents a very small market, the potential benefit in performance and reduced weight is significant, and leads to enabling improvements required by the Integrated High Performance Rocket Propulsion Technology (IHPRPT) program. DRX would replace Ni, steel or Ti in many of these applications, providing both a decrease in cost and weight. However, DRX would also have to compete with other candidate materials, such as Gr/epoxy, Be-Al and Ti on the basis of cost, risk, performance and manufacturing. A strong database would be required, including modulus, yield strength, fatigue properties (LCF/HCF), thermal properties (CTE) and fracture behavior data especially at high temperature. There is little or no interest in DRMg due to concern over corrosion. A summary of feedback from the hypersonic vehicles, missiles, and rocket industries is shown in Figure 5.

Liquid rocket engines require very high specific strength, resistance to cryogenic fluids and burning

- applications include inducers, impellers, pump motor housings, ducts
- RT is maximum use temperature for most applications

Missiles require high specific strength, stiffness

- Components include fins and wings, opto-mechanical assemblies, missile bodies

Applications generally require only limited life (<10 hrs)

ASSESSMENT: Several important opportunities for DRX

Figure 5. Missile and Rocket Applications For DRX

3.5 Electronics

This survey did not look into the potential of utilizing DRX for electronic applications such as heat sinks for chips. Previous studies have shown that commercial investment in materials for conventional electronic applications is so robust that government development programs have little to offer. In fact, DRA is currently being used as a thermal management material for power semiconductor substrates in hundreds of thousands of parts annually. Another interesting application of DRA was uncovered. The issue is vibration control in computer disk drives. All disk drives are driven by vibration requirements and incorporate constrained layer viscoelastic damping treatments which utilize a metallic constraining layer. Disks must have high specific stiffness for high resonant frequencies. Constraining layers must be still to be effective. Very low outgassing is required. High fatigue strength and fracture toughness are not required. Current DRA could be used for damping constraining layers and disk materials. This could be a large market for DRA if appropriate product forms could be produced (thin sheet and plate). Figure 6 summarizes this finding.

Survey of electronics applications not a focus of this study due to strong commercial research

- disk drive identified as attractive application for DRA

Disk drives are controlled by vibration requirements

- high specific stiffness required to increase resonant frequencies
- all disk drives incorporate constrained layer viscoelastic damping treatments. The metallic constraining layer needs high specific stiffness and very low outgassing

ASSESSMENT: Computer disk drives could be a large market for DRX. Current DRA could be used for damping constraining layers and disk materials. Sheet and plate DRA would be required.

Figure 6. Electronics Applications For DRX

3.6 Automotive

Automotive applications are strongly driven by costs. In the words of one respondent, magnesium and titanium are expensive even in nonreinforced forms. Machining costs are important. Toyota has published results demonstrating success at using a blended elemental approach to producing economically competitive DRTi [References 1,2], and auto valves are now bill of material on one Toyota model sold for the Asian market. However, this approach is limited by availability of sponge fines. DRA (Alcan, nonpowder) is used for castings and extrusions in parts such as propeller shafts, drive shafts and brake rotors. Honda uses a clever process which incorporates an Al MMC as the cylinder liner in the Prelude engine blocks. The MMC is infiltrated in the same step that the engine block is cast, significantly reducing manufacturing costs. Prototypes of pistons utilizing DRA with selective reinforcement with whiskers have been developed in an Army Tank Command program. A summary of feedback from the automotive industry is shown in Figure 8.

Automotive applications strongly driven by cost

- cast DRA (Alcan) used for casting and extrusion
- Mg and Ti are expensive even in unreinforced forms
- machining costs are important
- Toyota now using blended elemental approach for DRTi in valves

Several applications now exist for DRX

- driveshaft (Corvette, Chevy pick-up), brake rotors, integrally cast cylinder liners, auto valves
- prototypes of selective reinforcement with whisker DRA in pistons, for Theater Army Area Command (TAACOM)

ASSESSMENT: Automotive offers significant dual use market. However, cost and performance trade-offs may dictate different materials and approaches.

Figure 7. Automotive Applications For DRX

3.7 Military Equipment for Ground Forces

Feasibility studies have shown that DRX offers attractive properties for use in items of military equipment used by the Army. Properties of interest include wear and erosion resistance as well as increased modulus and strength. Potential applications include: large caliber guns, small arms, tank track shoes, helicopter skid pads, helicopter landing gear, and lightweight armor. The major impediment to wider use in these applications has been cost when compared to a baseline of steel or aluminum. A summary of feedback on Army military equipment is shown in Figure 9.

Definite interest in DRX for nonaerospace uses

- many structural applications
- cost has been the major impediment in the past, but recent advancements moderate this concern

ASSESSMENT: The Army has a broad range of applications and high interest in DRX.

Figure 8. Military Equipment Applications For DRX

3.8 DRX Suppliers

Each supplier advocated their own niche: DRA, DRTi, and DRMg. Limited quantities of present versions of DRTi and DRMg are being marketed now. The current annual market for P/M DRA is ~300,000 lb. Affordable secondary processing of current DRA materials is a major concern. Billet costs were reduced to $16/lb under the Title III program, but secondary processing pushes the cost up to ~$50/ lb. One respondent indicated that current DRA extrusions are not acceptable for use in the 400-500°F temperature range, but there is high temperature aluminum technology that has the potential of developing DRA capable of 700-900°F. Applications should be defined before designing a material. A summary of feedback from the DRX supplier industry is shown in Figure 6.

Each supplier promotes their own niche
High temperature DRA (200–300°C) of interest to several respondents
Secondary processing of DRA requires improvement

ASSESSMENT: High temperature DRA should be further investigated. What are the required properties and product forms? How would DRTi play against these requirements? Secondary processing of DRA could be a high payoff research area

Figure 9. DRX Supplier Feedback

4. RESEARCH COMMUNITY PERSPECTIVE

Respondents from the research community indicated that there was more to be done with DRA. Specifically a larger test program would help ascertain differences between DRA product forms. High temperature aluminum research should be renewed with the possibility of introducing new processing approaches, such as spray forming, for producing high temperature DRA at a reasonable cost. Additional effort to refine secondary processing would be beneficial. Matrix alloys should be optimized for discontinuous reinforcement and improvement in fatigue, fracture, and toughness properties. A summary of the responses from the research community is shown in Figure 10.

Properties of additional product forms for DRA requested
Interest in high temperature DRA
Fabrication (secondary processing) should be emphasized
Fatigue and fracture are important

ASSESSMENT: High temperature DRA, secondary processing and fatigue and fracture of DRA might be more important than emphasizing other matrices.

Figure 10. Research Community Feedback On DRX

5. ASSESSMENT OF PAYOFF AREAS

A review of the input information revealed a number of high interest areas and suggestions for future work. It also uncovered the technical issues of most concern by the users. It also made it clear that cost was highest on the list of issues. There is significant interest in the aircraft and spacecraft areas to encourage further development investments. The aircraft industry is most interested in development of HTDRA, continued improvement of DRA, especially to improve the fracture toughness and the possibility of DRTi. Additional requirements, information and trade-offs are needed to guide any investment.

The technical issues mainly have to do with the balance of properties developed in DRA and HTDRA. It is important that damage tolerance be achieved in this entire class of materials. In addition to the initial strength and modulus properties, an adequate balance of ductility, toughness, fatigue, fracture, creep, etc., must be achieved. It was suggested that processing be emphasized to achieve these goals.

There remains, for DRA and future HTDRA, the need for a comprehensive database and much better understanding of mechanical behavior.

A serious impediment to the widespread use of DRA/DRX is its cost, due primarily to the cost of the P/M approach used and subsequent fabrication and machining. A potentially low cost route to billet fabrication is spray forming. Spray forming, a recent processing technology, has gone from the research lab at Osprey Metals in England in the 1980s to full scale production in Europe in steel and to a lesser but growing extent in aluminum components. Large pieces, primarily preforms needing further working, are being produced for billets, plate, slabs, rings, rod, pipe, rolls, etc.

Spray forming is a process that atomizes metal from a melt, but does not further cool the atomized metal or allow it to solidify to make powder. Rather, while the spray is still semi-molten, it is deposited on a mandrel or substrate to make a low porosity preform suitable for further wrought processing. Spray forming is especially advantageous for materials that are difficult to process via ingot metallurgy since it prevents chemical segregation and provides very fine grain preforms. It is being used effectively in Europe for tool steels and high aluminum-lithium (Al-Li) alloys. It is being developed for difficult-to-work superalloys in the US as a much cheaper route than powder metallurgy. Applying spray forming to DRA is early in the research phase. Spray forming of titanium is only starting in research with no serious thought, yet, to DRTi.

Adaptation of spray forming to DRA is done by adding reinforcing particles to the atomized stream of molten metal either in the melt or in the atomizing gas. This is being experimentally explored in Europe and a few US establishments with promising results. Feasibility has been established. The potential of spray forming for DRTi is not receiving much development or even experimentation. Problems of contamination in melting and atomizing are serious. It appears that the use of the Duriron (now Flow Serve Corporation) cold wall induction furnace and the GE cold wall atomizing nozzle, plus rigid furnace and spray chamber environment control could allow it to work. The Toyota DRTi via powder metallurgy produces impressive properties. With spray forming it could be competitive.

Low cost approaches such as that described above are needed to achieve applications beyond niche uses. Secondary processing, fabrication, machining, and finishing costs must be reduced for widespread acceptance to be achieved. A comprehensive DRX development plan to attack these needs, formulated in concert with the aerospace industry, could provide the roadmap for success.

6. RECOMMENDATIONS

- Concentrate new development on HTDRA with emphasis on balanced properties. Get specific 'REQUIREMENTS' from serious users to guide the development.
- Expand the database and behavior understanding of DRA.
- Explore processing research to improve the balance of properties in DRA.
- Conduct detailed assessment of the possible applications of DRTi to determine if further development is justified and define specific ‘REQUIREMENTS’ for such a material.
- Explore cost reduction possibilities for secondary processing of DRA and HTDRA to include mill products, forming, fabrication, etc.
- Explore spray forming of DRA and HTDRA for significantly reducing the cost of billet, plate, sheet bar, and other preforms.

7. REFERENCES

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